REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-07-0373

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From – To)
	Final Technical Report	1 April 2005 – 30 October 2006

4. TITLE AND SUBTITLE
MISSE-6 Active Flight Experiment Program

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-05-2-0001

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Professor Harold G. Pippin

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Boeing Company
P. O. Box 3707 M/C 45-82
Seattle WA 98124-2207

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USAF/AFRL /NA
AFOSR
875 North Randolph Street
Arlington VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

12. DISTRIBUTION AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The original design criteria were to use battery power and self-contained data loggers for active experiments. About a year into the project, NASA decided that it was preferable for MISSE-6 experiments to draw power from the ISS power grid and minimize battery use. Due to continued high interest in flight experiment opportunities, the scope of MISSE-6 was increased to allow participation of several additional organizations. This required the use of two PECs to accommodate all the experiments. The Naval Researach Laboratory, The Air Foce Academy, NASA LaRC, and NASA MSFC added experiments. Sandia National Laboratory, Utah State University, NASA GRC, The Aerospace Corporation, each increased the scope of their individual experiments.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPONE NUMBER (Include area code)
Unclassified	Unclassified	Unclassified	Unclassified	19	(703)

Standard Form 298 (Rev 8-98)
Prescribed by ANSI-Std Z39-18

Final Report

Materials on the International Space Station – 6 (MISSE-6)

Cooperative Agreement FA9550-05-2-0001

Between USAF, AFRL
AF Office of Scientific Research
And
The Boeing Company

Gary Pippin

November 30, 2006

Table of Contents

Introduction

The Air Force Office of Scientific Research (AFOSR) sponsored MISSE-6 (materials International Space station Experiments-6) to provide an opportunity for academic researchers from two AFOSR-funded Multi-University Research Initiatives (MURIs), and additional groups from other AFOSR-funded programs, to conduct science experiments in Low Earth Orbit. To support this opportunity, Boeing was awarded a grant, as part of a cost-match agreement, to carry out activities required to achieve integration of the several experiments into hardware provided by NASA LaRC. Initially, the MISSE-6 experiments were to be distributed on two baseplates. The baseplates holding the experiments were then to be loaded into one Passive Experiment Carrier (PEC) at NASA LaRC. NASA was to carry out flight readiness testing and pre-flight safety checks, and then deliver the complete MISSE-6 package to KSC, where it would remain until launch.

The original design criteria were to use battery power and self-contained data loggers for active experiments. About a year into the project, NASA decided that it was preferable for MISSE-6 experiments to draw power from the ISS power grid and minimize battery use. Due to continued high interest in flight experiment opportunities, the scope of MISSE-6 was increased to allow participation of several additional organizations. This required the use of two PECs to accommodate all the experiments. The Naval Research Laboratory, The Air Force Academy, NASA LaRC, and NASA MSFC added experiments. Sandia National Laboratory, Utah State University, NASA GRC, The Aerospace Corporation, each increased the scope of their individual experiments.

The MISSE-6 package was approved during the 2006 DoD Space Experiment Review Board (SERB) meetings. Delivery of the integrated MISSE-6A and MISSE-6B packages to KSC will occur in August, 2007. The launch selected will occur in December, 2007.

Individual Experiments

Table 1 identifies the experiment organizations associated with each individual experiment and provides a correlation to the nomenclature of the MISSE-6 layouts.

Table 1. Experiment and Hardware Nomenclature and Experiment Organization.

Baseplate ID, Exposure	Experiment/hardware description	Experiment ID number	organization
PEC 6A, AO-UV side			
	Plasma Detector	A1	AFA
	MEMs	A2	Aerospace
	Composites	A3	Aerospace
	Thin films	B1	Boeing
	Datalogger	D1	
	Datalogger	D10	
	Datalogger	D11	
	Datalogger	D2	
	Datalogger	D3	
	Datalogger	D4	
	Datalogger	D5	
	Datalogger	D6	
	Datalogger	D7	
	Datalogger	D8	
	Datalogger	D9	
	passive frame	E1	Edwards
	passive frame	E2	Edwards
	MEMs	I1	Illinois
		L1	LaRC
		M1	MSFC
	Ballute	M5	MSFC
	Optics, solar cells	N1	NRL
		P1	Pittsburgh
		P2	Pittsburgh
	Metal coatings	Q1	Pittsburgh
	Metal coatings	Q2	Pittsburgh
	Metal coatings	Q3	Pittsburgh
	Metal coatings	Q4	Pittsburgh
	Piezoelectrics	S3	Sandia
	Sensor	S5	Boeing
	Thermocouple	T1	
	Thermocouple	T2	
	Thermocouple	T3	
	Thermocouple	T4	
		U1	USU
	passive frame	W1	MSGC
	passive frame	W2	GRC
	passive frame	W3	GRC

Table 1 (cont.). Experiment and Hardware Nomenclature and Experiment Organization.

Baseplate ID, Exposure	**Experiment/hardware description**	**Experiment ID number**	**organization**
PEC 6A, UV side			
		A10	AFRL
		A11	AFRL
		A17	AFRL
		A18	AFRL
		A5	Aerospace
		A6	Aerospace
		A7	AFRL
		A8	AFRL
		A9	AFRL
		B2	Boeing
	Datalogger	D12	
	Datalogger	D13	
	Datalogger	D14	
	Datalogger	D15	
	Datalogger	D16	
	Datalogger	D17	
	Datalogger	D18	
	Datalogger	D19	
	Datalogger	D20	
	Datalogger	D21	
	Datalogger	D22	
	passive frame	E3	Edwards
	passive frame	E4	Edwards
	passive frame	E5	Edwards
		G2	GRC
	MEMs	I2	Illinois
		L12	LaRC
		L8	LaRC
		M2	MSGC
		M3	MSGC
	Optics, solar cells	N2	NRL
	Calorimeters	P1	PSI
	QCM	Q11	ARC
		S4	Sensortex
	Thermocouple	T5	
	Thermocouple	T6	
	Thermocouple	T7	
	Thermocouple	T8	
	passive frame	W4	MSGC

Table 1 (cont.). Experiment and Hardware Nomenclature and Experiment Organization.

Baseplate ID, Exposure	Experiment/hardware description	Experiment ID number	organization
PEC 6B, AO-UV side			
		A15	AFRL
	POSS coatings	A16	Edwards
		A4	AFRL
	Datalogger	D23	
	Datalogger	D24	
	Datalogger	D25	
	Datalogger	D26	
	Datalogger	D27	
	Datalogger	D28	
	Datalogger	D29	
	Datalogger	D30	
	Datalogger	D31	
	EOIM holder	E6	MSFC
		G1	GRC
		G3	GRC
		L1	LaRC
		L10	LaRC
		L2	LaRC
		L3	LaRC
		L9	LaRC
		M4	MSGC
		N10	UC-MURI
		N11	UC-MURI
		N12	UC-MURI
		N8	UC-MURI
		N9	UC-MURI
	POSS/polyimide coatings	Q10	MSU
	POSS/polyimide	Q5	MSU
	POSS/polyimide	Q6	MSU
	POSS/polyimide	Q7	MSU
	POSS/polyimide	Q8	MSU
	POSS/polyimide	Q9	MSU
	piezoelectrics	S1	Sandia
	piezoelectrics	S3	Sandia
		S6	Sensor
	Thermocouple	T9	
	Thermocouple	T10	
	Thermocouple	T11	
	Thermocouple	T12	
		W6	AFRL

Table 1 (cont.). Experiment and Hardware Nomenclature and Experiment Organization.

Baseplate ID, Exposure	Experiment/hardware description	Experiment ID number	organization
PEC 6B, UV side			
		A13	ATEC
	passive frame	A14	ARC
	POSS films	A19	Edwards
	Datalogger	D32	
	Datalogger	D33	
	Datalogger	D34	
	Datalogger	D35	
	Datalogger	D36	
	Datalogger	D37	
	Datalogger	D38	
	Datalogger	D39	
	Datalogger	D40	
	Datalogger	D41	
	Datalogger	D42	
	Datalogger	D43	
	EOIM holder	E7	MSFC
		G4	GRC
		L11	LaRC
		L12	LaRC
		L4	LaRC
		L5	LaRC
		L6	LaRC
	Ballute	M6	MSFC
	Ballute	M7	MSFC
		N4	UC-MURI
		N5	UC-MURI
		N6	UC-MURI
		N7	UC-MURI
		S2	Sandia
	Thermocouple	T13	
	Thermocouple	T14	
	Thermocouple	T15	
	Thermocouple	T16	
		U2	USU
		U3	USU
	passive frame	W7	AFRL
	passive frame	W8	AFRL
	rad shielded TLDs	P4	PPI

Experiment layout

The allocation of exposure area for both the atomic oxygen exposed surface and the solar-only exposed surfaces of MISSE-6A and MISSE-6B is complete. The allocations and the arrangement of hardware on the underside (non-exposed) of the baseplates are shown in figures 1 through 8.

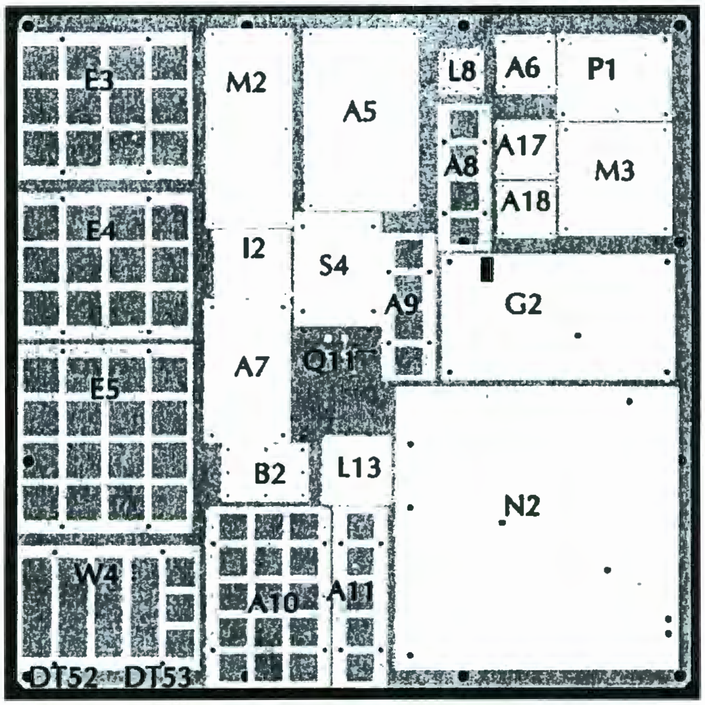

Figure 1. MISSE-6A UV exposure side showing representation of experiment layout.

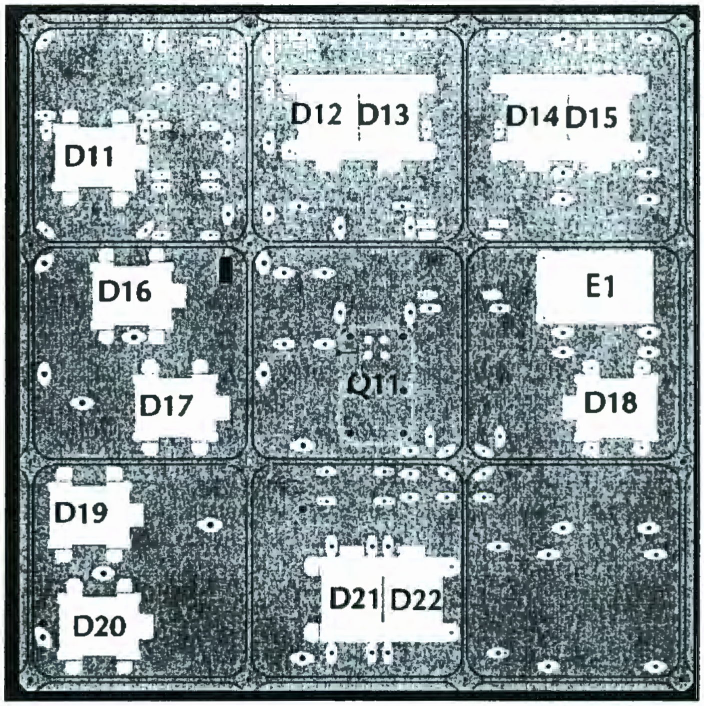

Figure 2. MISSE-6A –UV side, bottom side of baseplate, showing representation of hardware layout.

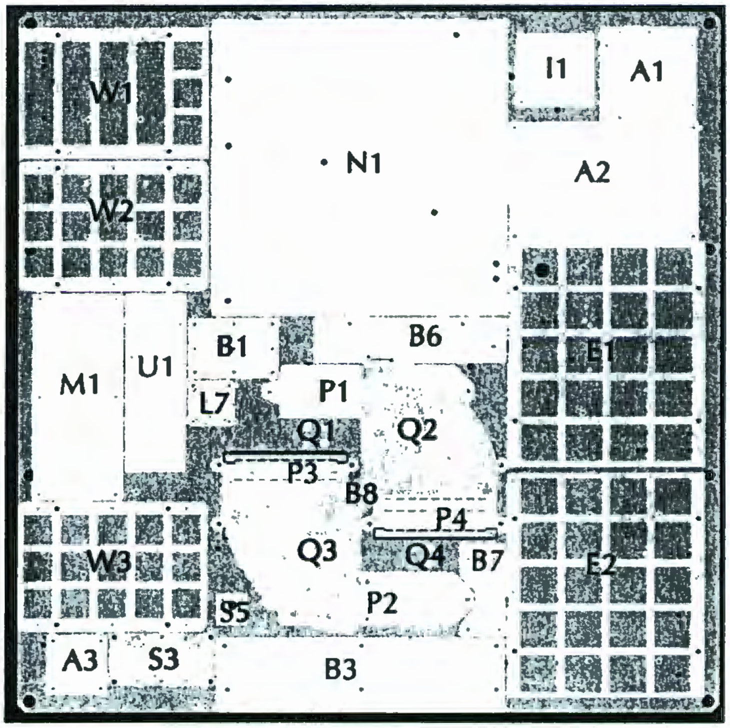

Figure 3. MISSE-6A AO/UV exposure side showing representation of experiment layout.

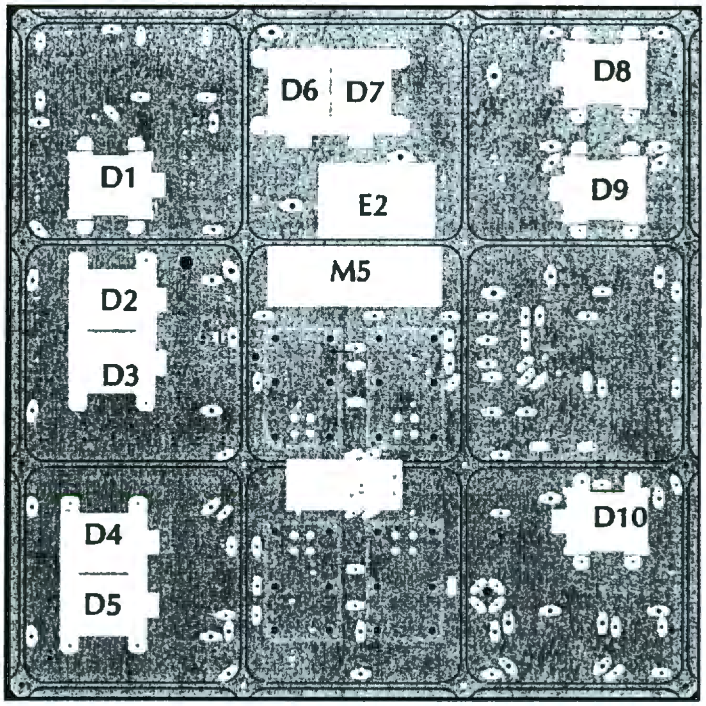

Figure 4. MISSE-6A AO/UV side, bottom of baseplate showing representation of experiment layout.

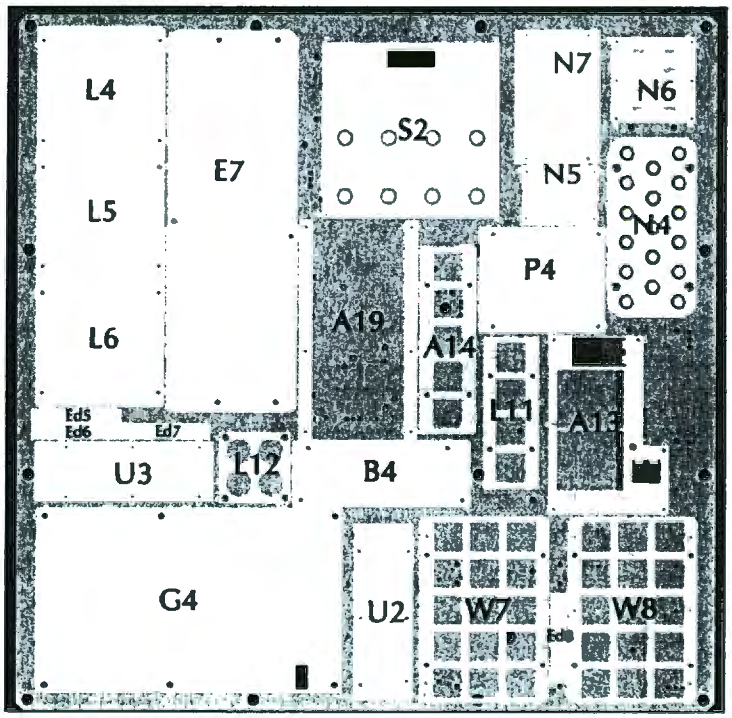

Figure 5. MISSE-6B UV exposure side showing representation of experiment layout.

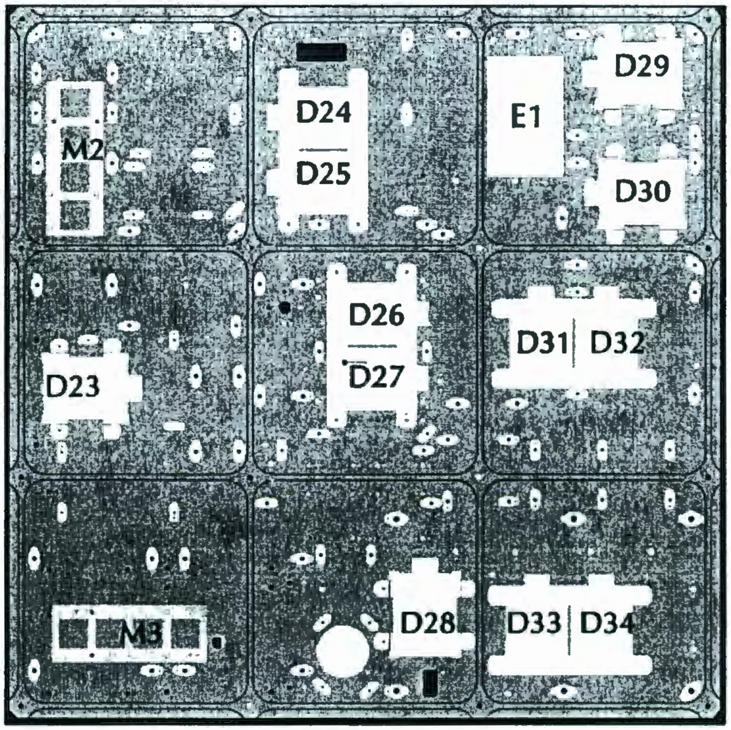

Figure 6. MISSE-6B UV side, bottom of baseplate showing representation of experiment layout.

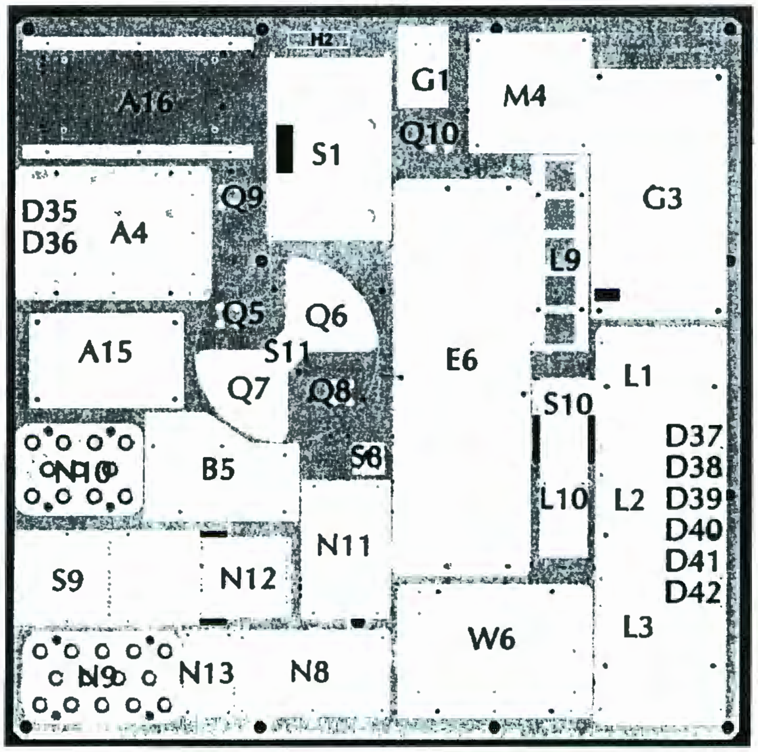

Figure 7 MISSE-6B VU exposure side showing representation of experiment layout.

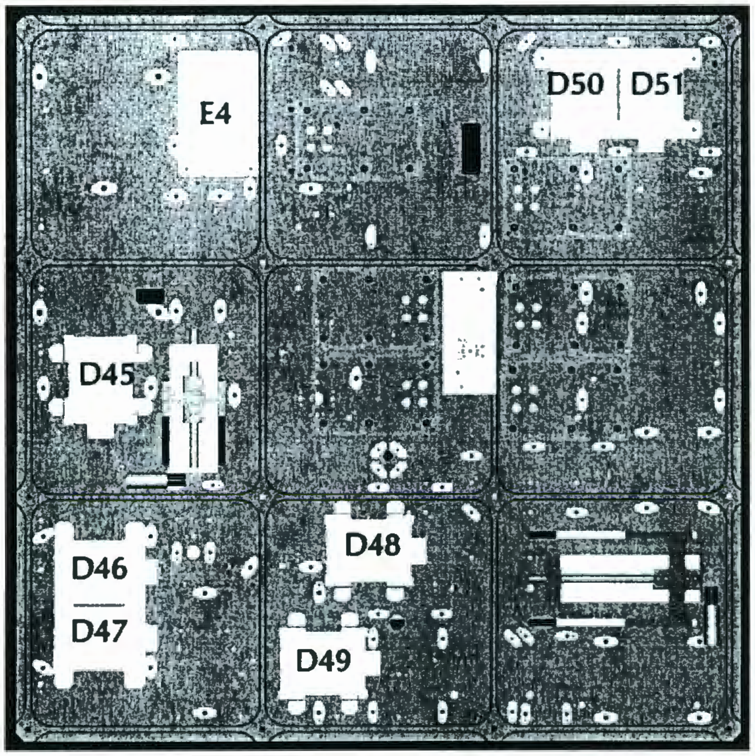

Figure 8. MISSE-6B UV side, bottom of baseplate showing representation of experiment layout.

Hardware Design and Manufacture

As part of the integration activities, Boeing was responsible for the design and manufacture of a series of passive sample holders, mechanical slides and shutters, Quartz Crystal Microbalance (QCM) assemblies, connectors and wiring for power and data transmission. Some of this hardware was built at Boeing, particularly the electronics; many of the mechanical assemblies were purchased and assembled, or machined at other locations.

Boeing modified the NASA LaRC QCM (Quartz Crystal Microbalance) hardware and circuit design by selecting some newer, more robust components and making the physical layout of the circuit more compact. Boeing, with the help of NASA MSFC, has built eleven packages, each package consisting of four QCM assemblies, for MISSE-6. Boeing provided QCM oscillator chips to Montana State University (MSU). MSU coated 24 oscillators with a selection of materials chosen in collaboration with AFRL-Edwards AFB. Boeing has arranged for an additional 16 QCM to be coated with materials selected by the University of Pittsburgh.

Figure 9 shows an example of the QCM mechanical assembly and electronics. The 4 coated flight samples are to the right. The smaller squares in the center contain one reference crystal each. The "beat" frequency (frequency difference between one coated

oscillator and its corresponding reference oscillator) will be periodically recorded using a space-qualified data logger. Changes in the beat frequency are largely due to mass and temperature changes. The thermal variation effects will be accounted for by pre-flight calibration and mass changes over time determined to evaluate the atomic-oxygen induced recession of the coatings. One set of 4 QCMs is mounted on the solar UV side to determine any solar-induced mass loss. The aluminum housing is the ground prototype; the 11 flight housings are being built by NASA MSFC.

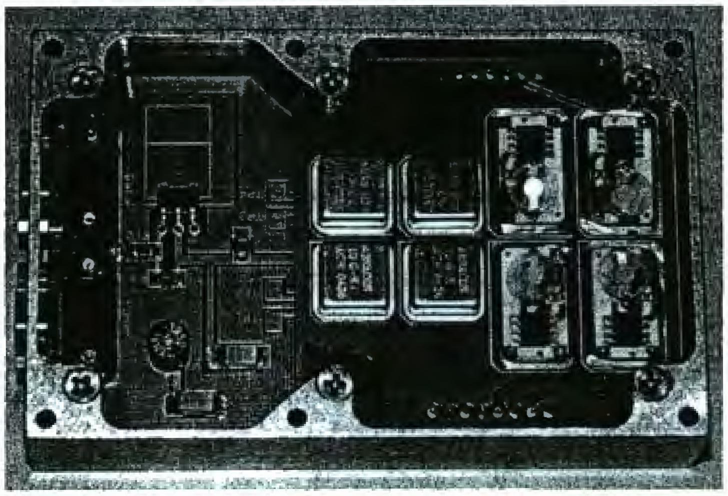

Figure 9. A set of 4 flight quartz crystal microbalance pairs in a prototype housing.

The data loggers selected for this flight experiment are the type flown successfully on MISSE-1 and MISSE-2. Figure 10 shows a typical Veriteq data logger, similar to those selected for use on MISSE-6.

Figure 10. A Veriteq SP-4000 data logger. The approximate weight is 60 grams.

Boeing designed and built two mechanical shutter assemblies to expose and protect individual specimens as MISSE-6 goes in and out of the Earths shadow. NASA MSFC built the actual shutter blades. Each 90^{o} rotation is initiated by a photo-sensor connected to the shaft motor circuit. Figure 11 shows the electronic circuits and mechanisms of the

smaller diameter (~6.5") rotating shutter assembly. A similar assembly with an ~9" diameter rotating shutter is being provided for the University of Pittsburgh experiment.

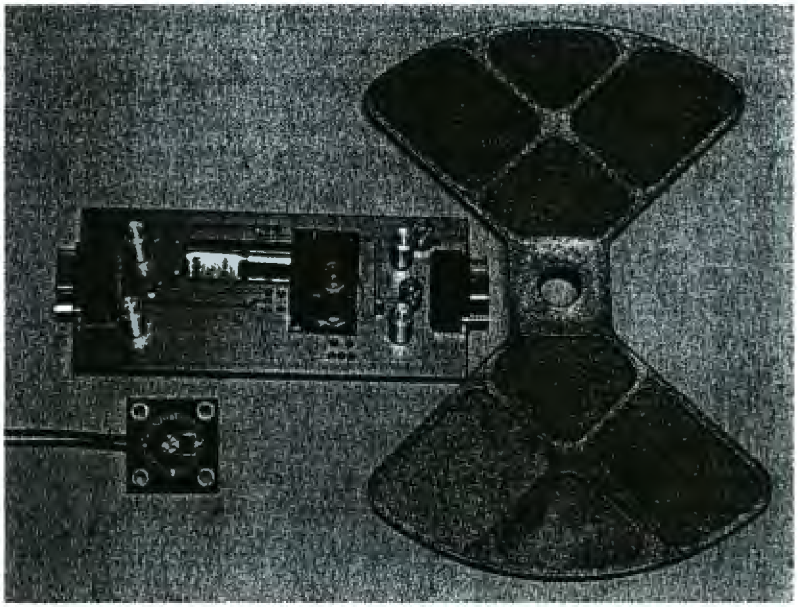

Figure 11. Small rotating shutter, motor and gear assembly, and associated sensor.

Boeing designed and built two mechanical translators, one for the University of Notre Dame, and one for NASA LaRC (under separate funding). The Notre Dame assembly will move in very small increments at intervals of ~8 minutes and travel a total distance of 3" in six months. The NASA LaRC slider will move four times, in 0.375" steps, with each step separated by ~62 days, for a total travel distance of 1.5". There are limit switches to prevent excessive travel by either mechanism.

Figures 12 through 15 show the mechanical translators and associated control electronics.

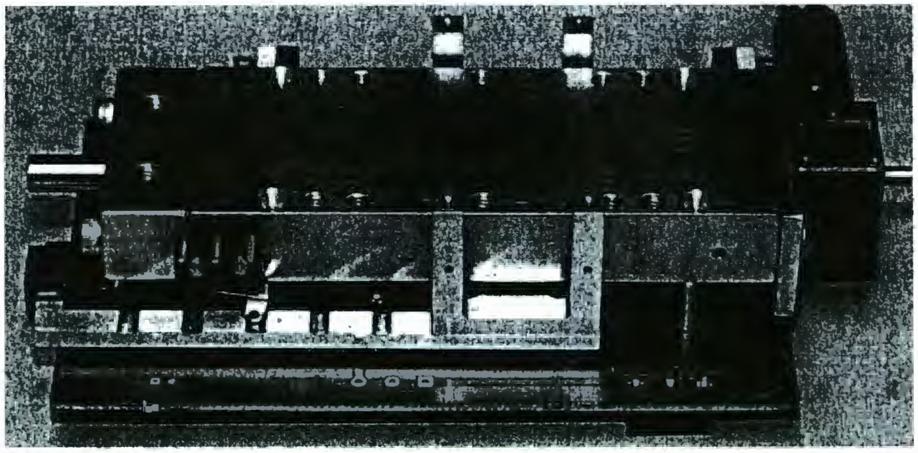

Figure 12. Motor, gear box, and mechanism for NASA LaRC translator. Electronics are underneath. Square posts will fit through opening in baseplate and sample cover will be mounted on the square posts

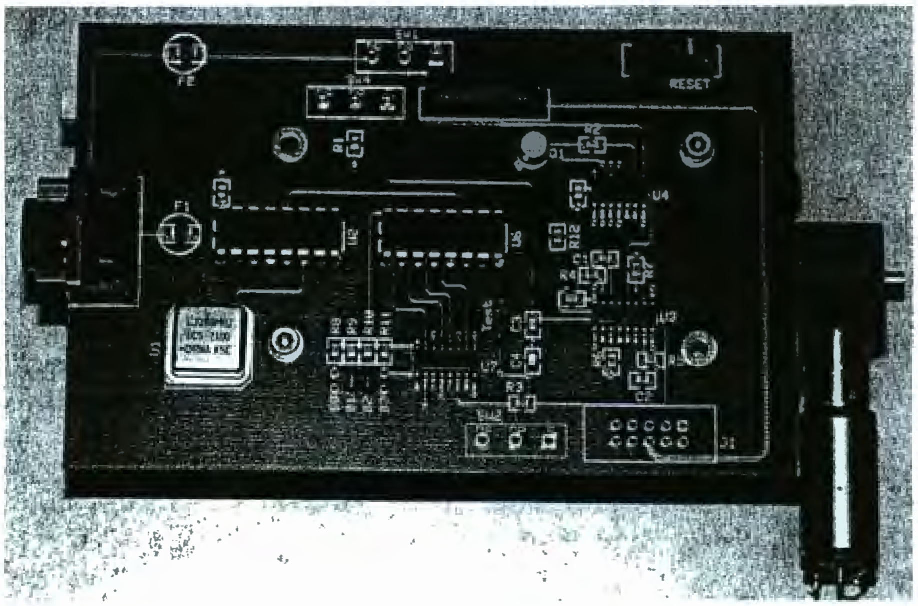

Figure 13. Electronics circuit, motor, and gear box for NASA translator.

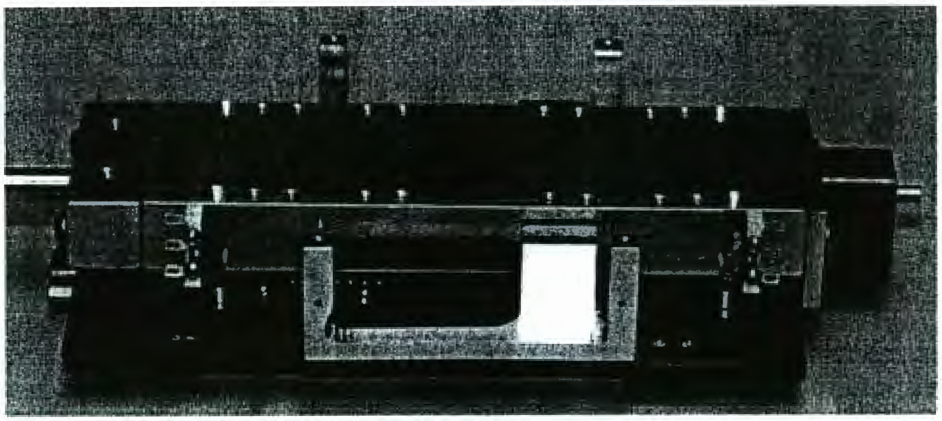

Figure 14. Notre Dame translator mechanism showing posts that will hold sample covers, gear box (red box to right), and limit switches to insure movement will stop after 3" travel distance is achieved.

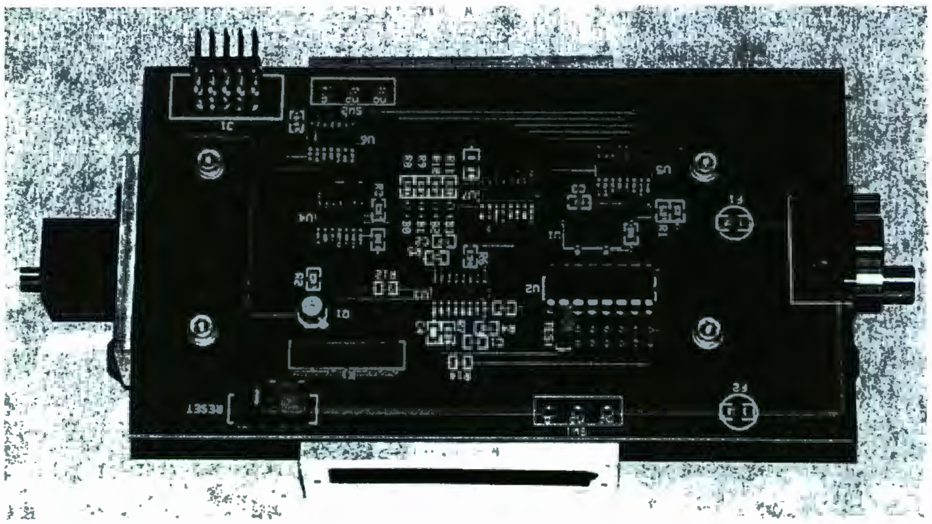

Figure 15. Electronics circuit for Notre Dame translator assembly.

The experiment base plates are previously used base plates from prior MISSE packages and other materials experiments. This hardware has been modified by NASA LaRC to accommodate the fastener pattern required for the MISSE-6 experiments, based on layout drawings provided by Boeing.

Boeing compiled the list of power requirements for the individual experiments and provided this list to NASA LaRC as input for their design of the power conditioning system. The power conditioning unit will convert the nominal 120V DC current from the ISS power grid to +-5 volts, +-15 volts, +28 volts, and +-50 volts. Experiments needing other voltage levels will have to provide their own converters. The electrical system is designed so that each experiment is fused so that a short or failure in one experiment will not shut off other experiments.

The passive sample holders are essentially complete and 90% have been delivered to LaRC. The remaining parts, built primarily to hold the most recently selected specimens, will be delivered to NASA LaRC by the end of December, 2006. NASA LaRC is providing silver-coated locking inserts for each sample holder to aid in the mechanical fastening of each part.

LaRC will provide the power interface for MISSE-6. Boeing has supplied connector cables to electrically connect the active experiments with the NASA power board. Boeing has supplied connectors and data loggers for selected experiments, particularly the MURI-teams and other organizations invited to participate by AFOSR.

Data acquisition rates and reset procedures need to be determined by the individual experiment teams. The data loggers will be individually programmed during the final assembly at NASA LaRC. Data loggers will be reset during the last access to the hardware at KSC prior to launch. This will allow the maximum use of data storage capacity during the on-orbit exposure period. Each data logger can store ~70,000 12-byte data points and will be programmed to stop data acquisition when the memory is full. Boeing is providing the connector cables to allow access to the data loggers without completely opening the containers.

T-type thermocouples will be used, based on their success on MISSE-1 and -2. The locations have been selected; there will be 4 thermocouples attached to each baseplate on MISSE-6A and MISSE-6B.

Development Schedule

Boeing has written a detailed draft of assembly procedures that has been reviewed with NASA LaRC. NASA LaRC will assume responsibility for the assembly procedures, edit the procedures as appropriate to meet the NASA QA requirements, and write the flight readiness test procedures (which NASA conducts). Verification of fastener torques shall be made with calibrated torque wrenches and inspections for sharp edges will be carried out during the assembly activities.

The hardware for each individual experiment was designed and built to meet the NASA safety requirements for launch in the Space Shuttle and deployment on the ISS. The system-level flight readiness testing at NASA LaRC will include a thermal vacuum test, vibration test, confirmation of acceptable outgassing limits, and functional electronics tests subsequent to the vibration test.

Experiments/hardware

The status of each experiment and major pieces of hardware are summarized below

1. Illinois- This hardware has been delivered to LaRC.

2. Utah State University- This hardware has been delivered to LaRC.

3. Sandia National Lab- This hardware has been delivered to LaRC.

4. AFA- The active low energy plasma measurement system has been delivered to LaRC.

5. ATEC- This hardware is built, and is undergoing final checks prior to delivery to LaRC.

6. GRC- This hardware is built. GRC personnel will hand deliver to LaRC and participate in the integration and functional test of their experiments.

7. LaRC- These experiments will be hand delivered at the time of assembly.

8. MSFC- The "EOIM-type" trays are being populated with 46 1" diameter individual specimens. The frames are built for the ballute materials under baseplate. Li/Al frames are built for Boeing/MSFC specimens. MSFC personnel will hand deliver experiments at the time of assembly.

9. Montana Space Grant Consortium – The passive samples have been delivered to LaRC. The active electronics test package will be hand-delivered at the time of assembly. A professor and students will participate in the integration of MSGC active hardware onto the baseplates at LaRC. Boeing has built and delivered sample holders for these specimens.

10. The Aerospace Corp.- The materials coupons and sample holder are built, and the MEMs experiment has been delivered to LaRC.

11. NRL-The hardware is built, and is undergoing testing prior to delivery to LaRC. NRL will participate in the integration of their experiment.

12. Sensortex-The samples are made and will be delivered by end of December.

13. AFRL- The AFRL/ML hardware and specimens and those of the invited teams have been delivered to LaRC. Boeing has built and delivered sample holders for these specimens.

14. U Chicago MURI- The hardware is built. Some samples are still under preparation. The experiment will be delivered to NASA LaRC by the end of December. At least one representative of the Notre Dame experiments will participate in the integration at LaRC.

15. Edwards AFB – The samples are produced and will be delivered by early December. Boeing has built and delivered sample holders for these specimens.

16. Shutters (Boeing) - motors and gear boxes are acquired and mechanical translation hardware assembled and undergoing tests to verify required performance features. Delivery to NASA LaRC will occur by end of January 2007. NASA LaRC has provided additional funding specifically for production of a mechanical translator for a NASA LaRC experiment.

17. QCMs (Boeing) – The flight electronics circuits are designed, built, and have been operated successfully. MSFC is building the aluminum containers for the QCM electronics and oscillators. Experimenters from Montana State University and the University of Pittsburgh have provided coated oscillators. Boeing will calibrate individual QCMs over the expected flight temperature range.

18. PSI- The calorimeter assemblies are produced and will be delivered to LaRC by end of December.

19. Boeing- Boeing and MSFC will provide reference materials for environment definition, including Kapton, Ag/FEP, and AZ93.

20. ARC- These specimens have been delivered to LaRC.

21. U Pitt MURI-Passive material samples have been purchased. Boeing has coated selected quartz oscillators for this experiment. Boeing has built sample holders for these specimens. This hardware will be delivered to LaRC by the end of December.

Summary

The final assembly and functional testing of the integrated MISSE-6 experiments will take place in the spring of 2007. Delivery to NASA KSC is scheduled for August, 2007 and the launch is scheduled for December, 2007. For planning purposes, the mission duration is set at 9 months. This time interval could change to an exposure period as short as 6 months, or as long as 1 year, depending on Space Shuttle launch schedules and EVA opportunities..